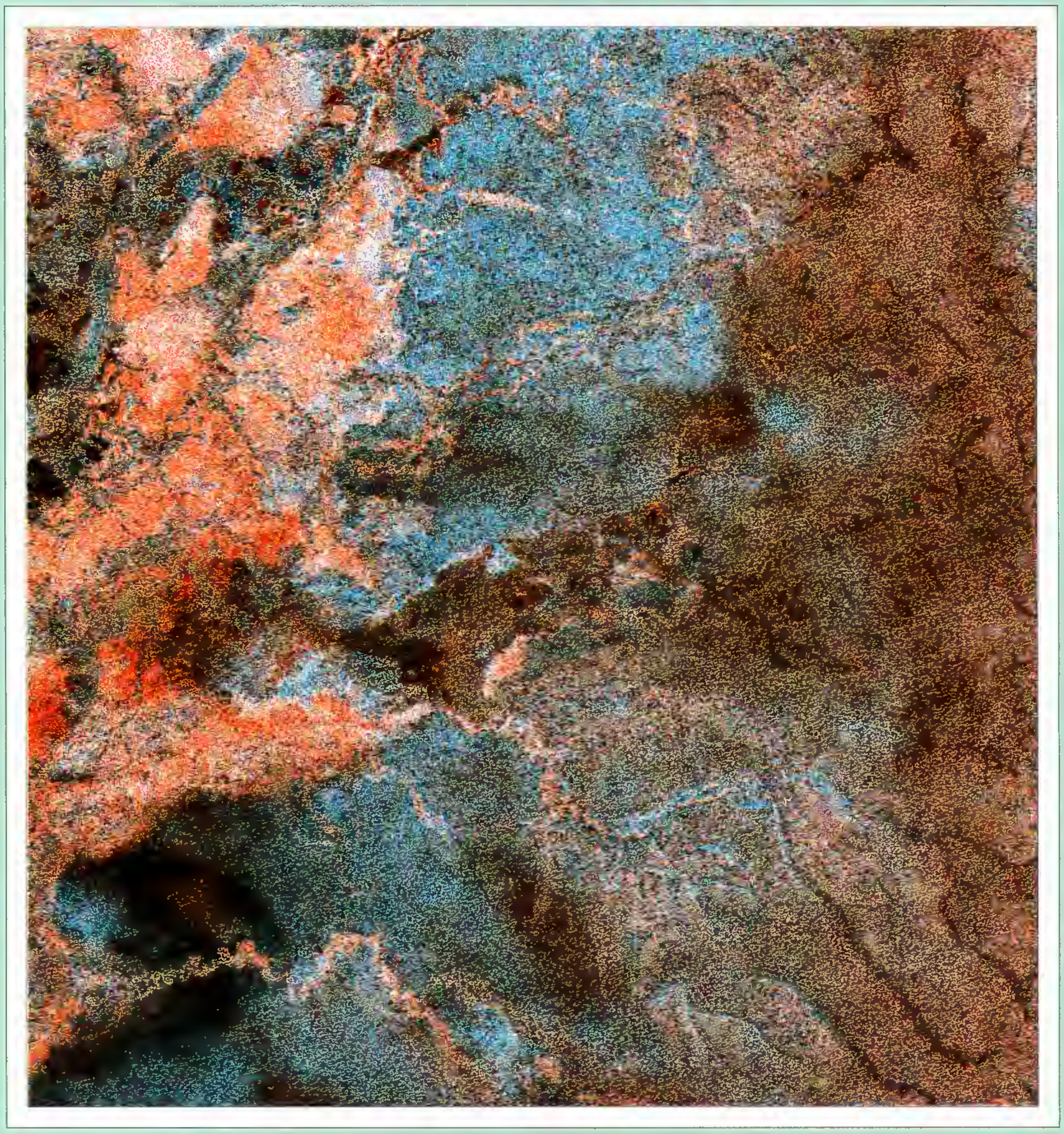
WETLANDS MONITORING BY ERS-SAR DATA
A case study: Lake Bangweulu Wetland System, Zambia



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Wetlands Monitoring by ERS-SAR Data

A Case Study: Lake Bangweulu
Wetland System , Zambia

by

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Food and Agriculture Organization of the United Nations

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ABSTRACT

Wetlands are a dynamic environment being affected both seasonally and annually by variable climatic conditions. Their surface area, often encompassing tens of thousands of square kilometres, is consequently subject to large variations. Monitoring wetland surface area fluctuations by traditional means is often difficult, time consuming and economically prohibitive.

Satellite remote sensing can provide baseline data at frequent intervals. The thermal inertia approach through NOAA AVHRR LAC data provides, at a low cost, a quite accurate assessment of the inundated areas, often covered with floating or water-rooted vegetation, but is limited by weather conditions, being applicable only to cloudless situations; ERS-SAR data provide very accurate information on all features of the wetland system, without weather restrictions. The two formats can work well together, providing different but complementary information.

NOAA AVHRR data should be used whenever clear sky conditions occur, mainly during the dry season. ERS-SAR data should be considered, as an alternative, when cloudy sky conditions are prevailing during the wet season, to provide essential data on wetland's expansion; moreover, they should be selected over limited areas crucial for assessing swamp fluctuations, for obvious economical reasons.

Keywords: hydrology, radar, remote sensing, wetlands

Acknowledgments

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INTRODUCTION

1.1 Study Objectives

Wetlands are an important natural resource, both as a local source of food and as a commercial enterprise of fishing. They are therefore a potentially significant source of income for the local communities. Africa has over 520 000 km^2 of large standing water bodies (Crul, 1992) and the possibility of sustainable development is vast, providing a reliable and profitable asset. As such...'accurate wetlands delineation would be of great value to managers of forest, wildlife and fisheries resources' (Hess et al, 1994).

The problem occurs when trying to evaluate the wetlands for their potential and their sustainability. Wetlands are a dynamic environment being affected both seasonally and annually by variable climatic conditions. Their surface area consequently is also in a dynamic state and, therefore, difficult to calculate accurately. A second problem is one of accessibility. Their very nature provides a problem of marshy ground and dense reed beds. Access via foot, land transport or boats is often restricted by such circumstances. In addition, wetlands are often quite large, covering areas of tens of thousands of square kilometers. This, combined with the above factors, leads to the conclusion that a ground survey can often be difficult, time consuming and economically prohibitive.

One of the alternative means of monitoring wetland systems that bypasses the above mentioned problems is the use of satellite data. The objectives of this study, therefore, were:

1. to assess the suitability of ERS SAR images in monitoring the seasonal changes of the wetland areas which are difficult to monitor on land, and
2. to carry out a comparison of the results obtained from both ERS SAR and NOAA AVHRR data. It has been a continuation of a previous study carried out by FAO (Travaglia et al, 1995) which examined the applicability of NOAA AVHRR images for assessing large wetland areas and monitoring their surface changes at periodic intervals. This study developed a thermal inertia methodology which is only applicable in situations without clouds.

1.2 The Bangweulu Wetland System

The location involved in this study is an area of wetland in the northern district of Zambia. Lake Bangweulu and its surrounding wetland is one of the three watersheds from the northern part of the eastern region of Zambia and is one of the largest wetland systems in Southern Africa. The catchment area has been estimated to be

120 000 km^2. The Bangweulu basin lies in an ancient craton where most of the water entering this region drains in from the south along Muchinga Escarpment and from the east from the border with Tanzania. Lake Bangweulu is thought to have a capacity of about 11 250 billion m^3 at high water with wetland waters rising and falling between 1-2 m at the center of the basin. This annual rise and fall causes the peripheral areas to become flooded during the wet season; in the dry season, as the waters recede, these areas become, once again, dry. This floodline, in some sectors of the wetland system, advances and recedes by as much as 45 km within one annual cycle.

The large permanent wetland and seasonally inundated floodplain lie to the northeast and southeast of Lake Bangweulu. This area contains shallow water bodies, a network of channels and several islands. The vegetation in the shallower waters is mainly composed of *Cyperus papyrus* and reed beds constituted of *Phragmites mauritianus* and *Eleocharis dulcis*. The *Cyperus Papyrus* reach height of 4 m and form mono-specific stands. The reeds reach an average height of 4 m but with individual plants reaching 8 m particularly in deeper water areas . The deep water areas have floating vegetation including *Eichornia crassipes*, *Aeschynomene fluitans* and *Ipomoea aquatica*, among many other species. The permanent savannah surrounding the wetland system consists of shrubs, trees and grasses.

The climate in Zambia is one of tropical wet and dry seasons. These seasons consist of a cool dry season from April to August; a hot dry season from August to October; and a warm wet season from November to March. Sporadic light rains usually start in September/October with the principal rains arriving in December and continuing until March. The winds at this time are northerly or north-westerly and consequently the rains start in the north and move south with precipitation decreasing from north to south. The wet season remains until March when cool, southerly winds prevail across Zambia. Mean annual precipitation is between 1100-1500 mm, but there are variations such as the severe rain in 1978 and drought which affected many parts of Southern Africa in 1992 (Fig.1).

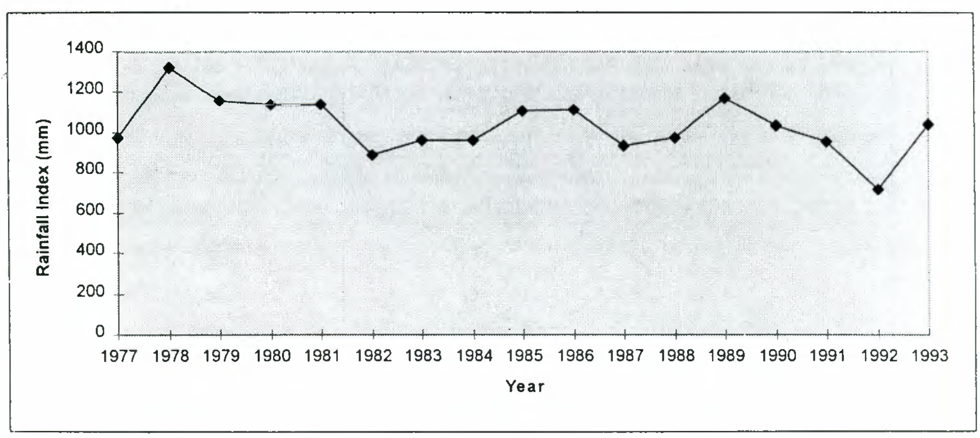


Fig.1: Rainfall in Zambia (Gommes and Petrassi,1994)

The following information was derived from Vanden Bossche and Bernacsek, 1990.

Table 1: Geographical data

Name: Lake Bangweulu wetland system

Location: Zambia- 10° 15′ - 12°30′S; 29° 30′ - 30° 5′ E

Altitude: 1 160 m

Surface Area:

Lake Bangweulu and adjoining lakes		2 735 km^2
Swamp and floodplain		12 271 km^2
Lake islands		218 km^2
Swamp islands		235 km^2
Open waters in swamps		334 km^2
	Total	15 793 km^2

There was no information on what period of the year the preceding area data was based on; it is assumed to be the wet season.

1.3 Why Bangweulu

Lake Bangweulu and its wetlands were originally chosen for a number of reasons. The main reason was its inaccessibility. It is a prime example of a wetland with few access routes. For this reason, it is far less well known than other wetland systems of comparable size in Southern Africa, and as such is an under exploited resource. Its potential, however, could be great and needs to be assessed to maintain a balance between under and over exploitation before any development project is implemented.

Another reason is that, despite the difficulty of access, some study has already been carried out and a ground project is presently being conducted by the World Wildlife Fund. This provides us with some sort of framework upon which our results could be assessed. Furthermore, in the previous study (Travaglia et al, 1995) it was found that the Bangweulu wetland system is frequently covered with clouds and consequently difficult to study with NOAA AVRR thermal inertia approach. It was, therefore, considered an ideal area to study with ERS SAR (Tab. 2).

Table 2: ERS SAR geocoded product characterisitics:

Pixel Size (Easting)	12.5 m
(Northing)	12.5 m
Spatial Resolution	30 m (in Easting and Northing directions)
Scene Area	100 x 100 Km rotated according to map grid
Product location accuracy	better than 100 m in areas with low relief
Projections	UTM at latitudes within - 70/+70°
	UPS outside (under ERS coverage)
Ellipsoid	WGS 1984

1.4 RADAR Detection of Inundated (Vegetated) Areas

For some years research work has been undertaken on wetlands monitoring based on microwave (Waite et al., 1981; Pope et al., 1994; Stofan et al., 1995), which has increased after the launch of the European ERS-1 and the Japanese JERS-1 satellites (Yamagata and Yasuoka,1993). In this section, some recent work on the subject of RADAR application to wetlands monitoring will be considered in order to give grounds to the results presented in this report.

This study mainly concerns the possibility of discriminating, with ERS SAR images, both vegetation (water-rooted or floating at the water surface), and bare flat sandy areas. As regards the wetland vegetation... 'the ability of Synthetic Aperture Radar (SAR) to detect flooding beneath a plant canopy has been demonstrated for a wide variety of herbaceous and woody vegetation types' (Hess et al., 1990). Other projects which support this statement have been carried out based on SIR-C/X SAR data, aimed at detecting the extent of flooding in tropical Amazon wetlands rich in species (Wang et al., 1994).

It has been found that, in general, flooded vegetated areas show a higher radar return, as compared to non flooded ones. This...'results from double-bounce reflections beneath smooth water surfaces and tree trunks of branches' (Hess et al., 1990). A wide variety of cases of enhanced backscattering from inundated vegetated areas is reported in the Hess et al. (1994) paper which considered various sensors, flown on aircraft, shuttle or SEASAT.

These results however should be interpreted with care. The explanation, mentioned above, involves that the canopy/ground scattering mechanism is the dominating one in the interaction with the electromagnetic (e.m.) radiation. In general, the canopy/ground interaction depends on the wavelength, the polarization, and the incidence angle of the impinging radiation, as well as on the vegetation cover geometry and its density.

Lately some applications of ERS SAR imagery to wetlands areas classification have been reported in the literature (Yamagata and Yasuoka, 1993; Kux and Henebry, 1994). They explored the effectiveness of alternative approaches to the conventional maximum likelihood supervised classification method. These methods are aimed at extracting texture information for land cover classification and environmental monitoring.

Yamagata and Yasuoka (ibid) carried out a comparative study over the Kushiro mire (Japan). A JERS-1 and an ERS-1 SAR images were compared to a SPOT image (all geometrically corrected) in order to explore the usefulness of SAR data for wetland areas classification. In particular, they tested the effectiveness of some indexes, derived from the coocurrence matrix, for texture features identification. From their results, it appears that in general in JERS-1 images wetlands vegetation classes can be well identified; whereas, fens and swamps can be better discriminated over ERS-1 images. (Swamps were classified as covered mainly with alder, *Alnus japonica*; fens as covered mainly with reeds, *Phragmites communis*).

From the above considerations, it appears that there are some grounds supporting the discrimination of inundated vegetated areas over SAR images.

In case of bare, flat, dry, sandy areas, the expected image tone is very dark gray. In the present study such sandy stretches should be detectable with ERS SAR images, when there is enough vegetation over inundated water surfaces to produce a high backscatter return. This will then allow a clear distinction between the two surfaces.

The discrimination between smooth water surfaces and bare sandy soil is of little concern in this report as they rarely occur together in the study area. Indeed, usually as soon as an area is inundated, vegetation, either water-rooted or floating on the water surface, spreads quickly.

1.5 Wetland Monitoring : Data Requirements

In this section we address the issue concerning the data supply availability and continuity. As described in the study, the wetlands monitoring methodology is based on two products:

1) AVHRR LAC products (high resolution)- Channels: 1,2,4;

2) ERS-SAR images.

The former products should be used whenever clear sky conditions occur, mainly during the dry season (thermal inertia approach). The latter products should be considered, as an alternative, when cloudy sky conditions are prevailing during the wet season; moreover, they should be selected over limited areas, crucial for assessing swamp areal fluctuations, for obvious economical reasons.

ERS SAR data suitability for wetland monitoring

ERS SAR holds promise for this, initially because of a number of aspects:

1. this type of data is weather independent i.e. information can be obtained even when the area is covered with clouds or there is rain. Another feature is that the system emits its own radiation and, therefore, is also sun independent.
2. the wetlands are usually flat areas and, therefore, the geometrical distortions are negligible.

AVHRR LAC product availability

AVHRR LAC products are available from NOAA satellite series.

For the present study, the thermal channel has to be acquired early in the afternoon, when the temperature contrast between dry and wet surfaces is expected to be relatively high. At present, useful data are those acquired from NOAA 14 with p.m. Equatorial crossing time (ascending pass).

The implemented methodology is based on continual supply of AVHRR LAC data, especially during the dry winter period (April to August). AVHRR LAC high resolution data are continuously transmitted and can be acquired wherever a ground station is available. On the other hand, only a limited amount of LAC data (about 10 min/orb) can be stored on board and then become available in the NOAA archives.

Time Consideration:

Wetland monitoring requires seasonal estimates - at least twice a year- to be carried out when seasonal extremes are expected to occur, i.e. towards the end of the wet/dry season.

Alternative ATSR data usage:

As an alternative, the possibility of using ATSR data has been considered. Due to ERS-1-2 Equatorial crossing time (about 10:30 - 22:30 hours) the thermal channel appears not to be suitable for this type of analysis. The visible and near infrared channels could be used for deriving the NDVI. ATSR data are, at present, of difficult accessibility .

ERS-1-2SAR data availability

ERS SAR.GEC (geocoded) products appear suitable for wetland monitoring.

ERS data supply over the areas of interest is guaranteed by the presence of a SAR receiving station in South Africa. In addition to this, some acquisition campaigns are planned over the Libreville visibility area, in Gabon, where a portable station is deployed during limited periods.

Time Considerations:

Off-line products, which are available after a few weeks from acquisition, should meet the time requirements.

CHAPTER 2

METHODOLOGY

2.1 Data Used

Two sets of satellite data were used to fulfill the purpose of the study, namely NOAA AVHRR and ERS-SAR data. To meaningfully compare results obtained from the two approaches during the dry season, NOAA and ERS data were selected as having been acquired within the shortest time frame, ideally in the same day.

Table 3: Data set table

NOAA AVHRR

Image Number	Date	Time	Pixel Resolution
1	28/6/94	14.39	1 100 m

ERS SAR Dry Season

Image Number	Date	Time	Pixel Resolution
1	15/6/94	08.12	12.5 m
2	15/6/94	08.12	12.5 m
3	15/6/94	08.13	12.5 m
4	5/7/94	08.10	12.5 m
5	5/7/94	08.10	12.5 m
6	5/7/94	08.10	12.5 m
7	2/7/94	08.15	12.5 m

ERS SAR Wet Season

Image Number	Date	Time	Pixel Resolution
1	7/12/95	08.12	12.5m
2	19/11/95	08.09	12.5m

2.1.1 NOAA AVHRR

The first data set consisted of one non-georeferenced NOAA AVHRR image acquired on 28 June 1994, in the dry season. Only one AVHRR image was required because of its pixel resolution of 1 100 m which permits the single image not only to cover the area of Lake Bangweulu but also to include most of Zambia. This was needed as verification and comparison with the ERS SAR images.

Rationale

The thermal bands provide a means to measure the resistance of bodies to changing temperatures with time. This can then differentiate between bodies such as water and aquatic vegetation, which have a high thermal inertia and, therefore, have a more uniform surface temperature with time; and bodies, such as dry land and non-aquatic vegetation, which have a low thermal inertia and, therefore, a varying surface temperature with time. For this reason, the time of acquisition is very important, the best time being in the early-afternoon when the differences between the bodies described above are at their greatest. Consequently, the aquatic and non-aquatic environment can be distinguished and an estimate of area can be established.

Another utility of AVHRR images are their visible and near infra-red bands which can be used for the Normalized Differences Vegetation Index. Vegetated areas appear in white or light grey and non-vegetated areas appear dark. This can be used to clarify ambiguous situations, and to calibrate the thresholding process.

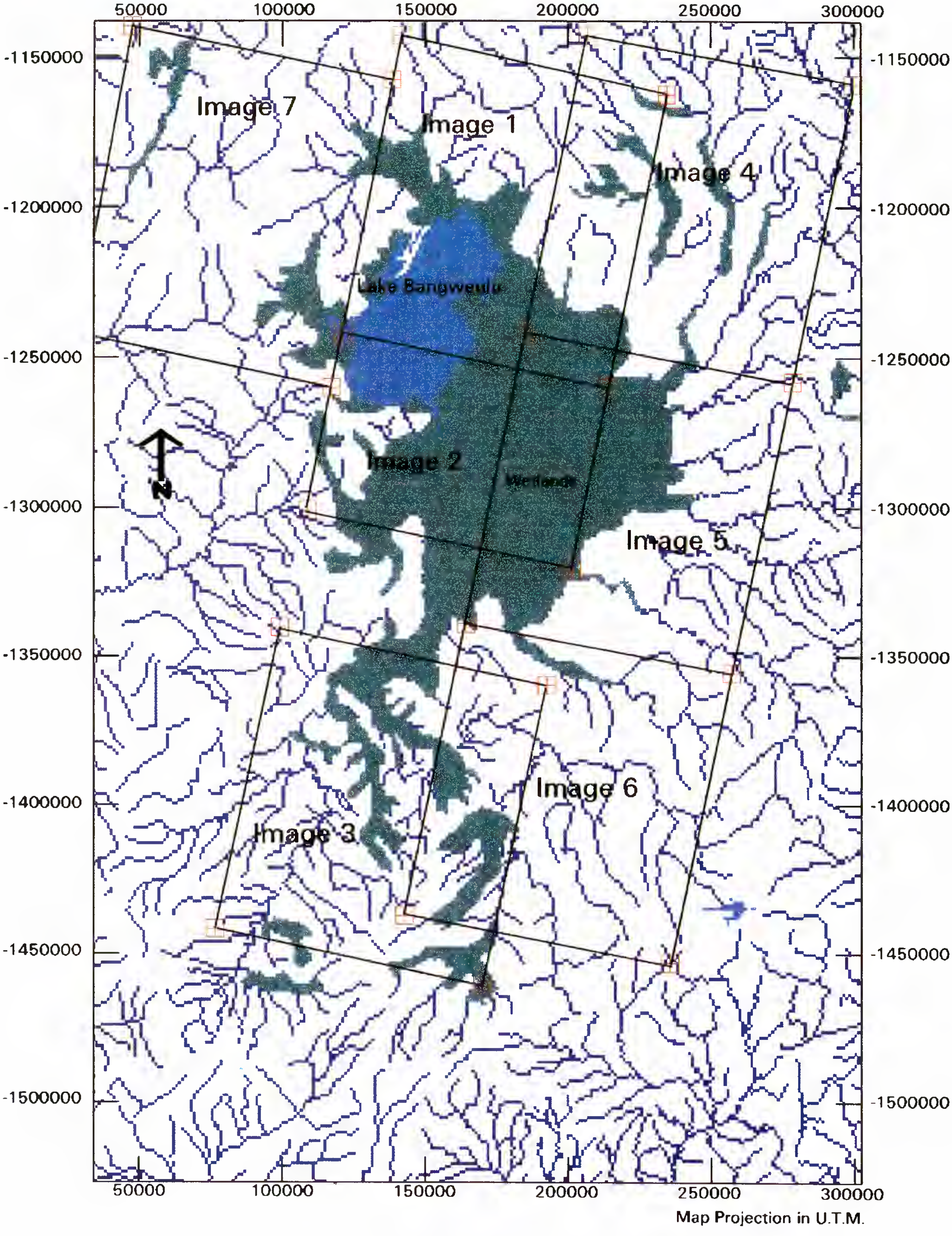
2.1.2 ERS SAR

The second data set involved 7 SAR geocoded images acquired in June/July 1994 (Fig 2), during the dry season; and two SAR geocoded images acquired in November/December 1995 (Fig 3), during the wet season. Seven images in total were needed for the dry season to cover the same area as the AVHRR image of the whole wetland. The reason for this greater number was mostly due to the pixel resolution of the images which is 12.5 m, but it was also due to the frame positions. Overlapping images cause unnecessary doubling of information whilst on the other hand some images only show a very small but essential part of the wetland.

The two images of the wet season were acquired as a means of determining the accuracy of our assessments and also as a guideline as to the state of the wetland with the rains. The choice of the date was perhaps not as suitable for the wet season. A more accurate picture would have been depicted by images acquired in March 1995, at the end of the rains, which unfortunately were not available. However, the images provide an indication of what happens in wet season. Geocoded images were chosen in preference to precision images because the limited time of the project did not allow for the georeferencing of 9 images.

Rationale

1. Radar return is generally very dependent on the ground surface roughness and dielectric properties.
2. The rougher and the wetter the ground surface, the higher the backscatter return. The radar return varies depending on the impinging e.m. radiation.



Positions of Seven ERS SAR Images Covering Lake Bangweulu and Surrounding Wetlands, Zambia, in the Dry Season.
(15/6/94 - Images 1,2,3 : 5/7/94 - Images 4,5,6 : 2/7/94 - Image 7)

Fig. 2

For example water surfaces appear dark due to the prevailing specular reflection of the e.m. signal. However, wind (greater than 3-4 m/s) generates waves which affect the surface roughness, increasing the radar return. This effect increases with increasing wind velocity and saturates up to velocities of about 24 m/s. Wind can also increase the roughness of vegetated areas especially where herbaceous species are present. Transient weather conditions can affect the signal. Although radar imagery is relatively independent of the cloud coverage, precipitation affecting the ground surface roughness/dielectric properties, can hamper land cover detection.

The effects of weather conditions, such as described above, have to be considered in order to evaluate their influence on interpretation /classification results.

Vegetated areas show generally a radar return higher than smooth, bare and dry soils. In the case of inundated vegetation the radar return is expected to be higher than in the case of non-inundated vegetation. This is briefly illustrated in the following section.

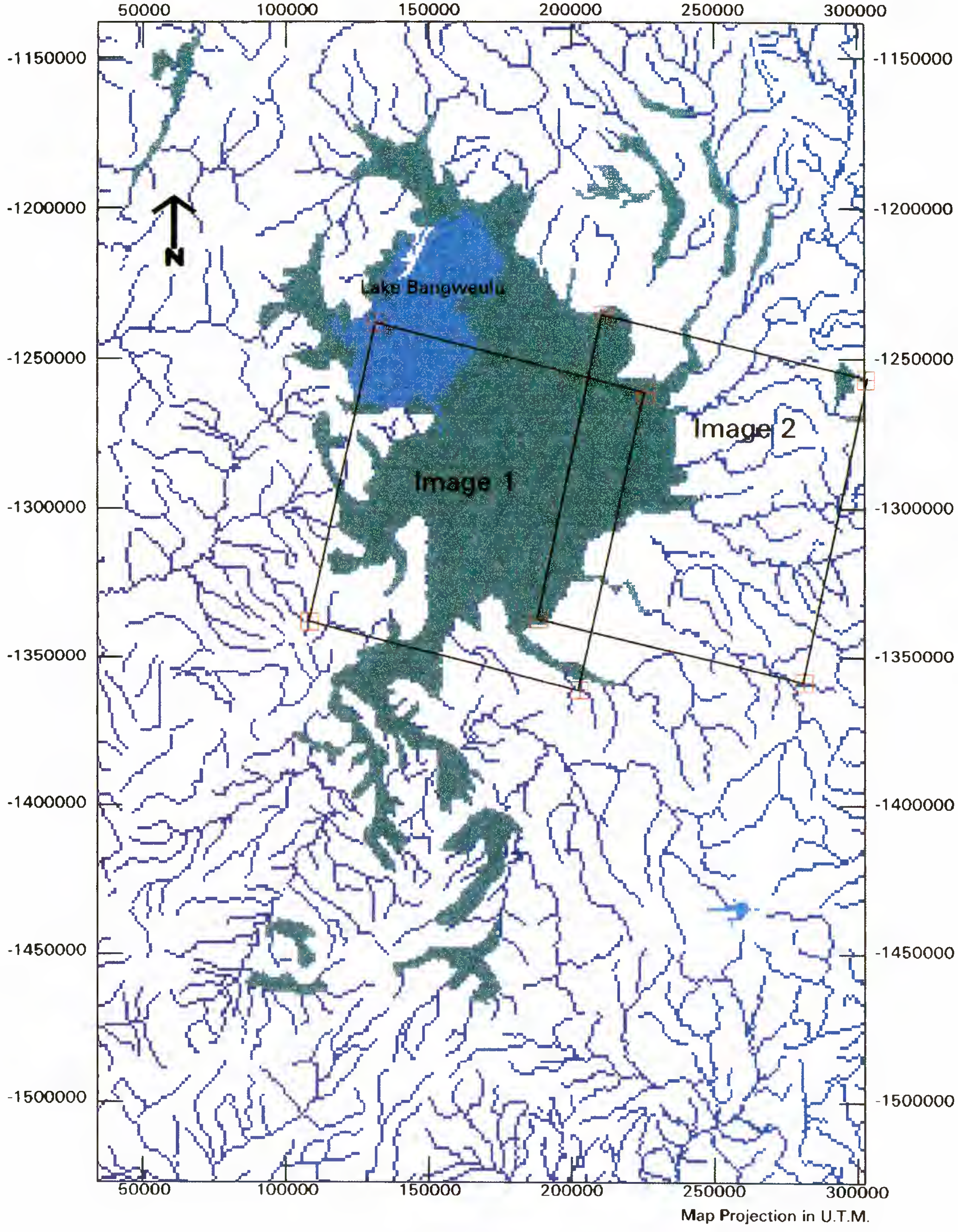
Expected SAR image tone variations

Below are presented some typical land covers of the area of study with the corresponding expected grey tones of a SAR image.

Land Cover	Image Tone
Bare soils	from very dark grey (dry, flat soil), to a light grey (wet, rough soil)
Free water surface	from very dark grey (still water), to bright (windy conditions)
Vegetation rooted in shallow water	grey/bright
Vegetation floating on the water surface	light grey

It would appear that if smooth water surface and a dry bare soil (relatively flat) surface are present at the swamp edge, they cannot easily be discriminated. These critical conditions are likely to be present during an early stage of the water encroachment in the wet period; or else if shallow pools without vegetation are formed during the dry period.

Some of the above mentioned transient effects can be avoided if suitable times for detecting the maximum/minimum extent of the wetland area are selected. These would be the end of the wet and dry periods. This would sometimes be difficult with the changing rain patterns from year to year.



Positions of Two ERS SAR Images Covering A Part of Lake Bangweulu and Surrounding Wetlands, Zambia, in the Wet Season.
(7/12/95 - Image 1 : 19/11/95 - Image 2)

Fig. 3

2.2 DATA Processing

NOAA AVHRR

The AVHRR image was imported into ERDAS Image version 8.1 and was georeferenced firstly to the ONC maps N4 and N5 (scale 1:1 000 000) to the latitude/longitude projection by using the grid overlaid onto the row image by the supplier. This grid, however, caused the values of the displayed pixels to be compressed in some way and the image could not be displayed clearly. This problem was solved by importing the image without the grid and georeferencing it to the image with the grid. The image was then converted to the U. T. M. projection to be comparable with the ERS SAR images. A thresholding technique (Travaglia et al, 1995) was performed to highlight the differences within the thermal band 4 between the aquatic and non-aquatic environments. The Normalised Difference Vegetation Index process was performed on the visible and infra-red bands to calibrate the thresholding of the thermal band.

ERS SAR

The geocoded images were imported into ERDAS Imagine version 8.1 and were then rescaled to 8-bit for two reasons. Firstly, the amount of space available on the computer was limited and secondly, importing a final image into tiff format requires an 8-bit image. All the images were processed using the speckle suppression which removed speckle and clarified the edges of the different classes. An edge detection process was also carried out but there was little improvement and, therefore, it was considered unnecessary.

Both the AVHRR image and the SAR images were individually displayed in ARC/INFO version 7.03. A coverage was created for each image and the borders between the inundated areas and bare soil, and the bare soil and the savannah were identified and digitised. The coverages were built into polygons and their areas were calculated automatically. The coverages were then exported to an e00 format and imported into ERDAS as an ArcCover. These were overlaid on the image once more.

Interpolation of Missing Data

As a result of forty percent of missing data from one of the dry season images, a part of the area of the wetland could not be directly calculated. To solve this problem a comparison of the wet season image which partially covered the missing area and the AVHRR image was performed. From this it could be seen that the wetland's perimeter in this particular area had not changed between the dry and wet seasons. It was decided, therefore, to use the SAR wet season image to establish the location of the borders. To do this, a union of two of the arc covers, above and below the missing data, was performed. The wet season image was displayed in ARC/INFO and the unionised cover was superimposed. The borders were then digitised.

Multitemporal Image

A first principal component image was created using image 2 of the wet season. This was created to fill the third band in the multitemporal image. The multitemporal image was then produced by layerstacking the common areas of image 5 dry season, image 2 wet season and the first principal component image. Both the wet season and dry season images were used to create a first principal component image and then used in the layerstacking process. The wet season image was found to create a clearer end result and, therefore, was used in the final image.

Validation

In order to validate both the AVHRR and the SAR based metodologies, some field data must be analysed. This can be done with photographs, particularly aerial, showing the area at the end of both wet and dry seasons. A field campaign is foreseen consisting of the calculation of control points along the border of the inundated area by the use of GPS. This will be compared with the results achieved by both the AVHRR and SAR data processed according to the methodologies indicated in this study. The field campaign must necessarily be done almost simultaneously with the acquisition of the satellite data.

CHAPTER 3

RESULTS

3.1 Dry Season

Classification

The classification of a SAR image concerns the backscatter return. The different levels of return can be interpreted as different classes mainly of vegetation coverage (see Methodology). All the SAR images were classified in this way.

An example of the different classes is shown in the figure of the detail of image 5 (Fig. 4). The darker patchy area to the left of the image has a mixed return, the areas of low backscatter return characterise a smooth surface and have been classified as open water. The lighter areas correspond to a slightly rougher surface and can be categorised as open water with vegetation. This whole area is the deep water zone.

The brighter areas in the centre of the image correspond to high backscatter return and therefore to a rough surface. These areas have been classed as reed beds and papyrus which inhabit the fringes of the permanently inundated areas.

The dark areas to the right of these represent a low backscatter return and therefore a smoother surface. From previous knowledge and comparison with NOAA AVHRR NDVI we can discern that the areas were once covered with water and most probably with vegetation. The water, when the wet season ended, gradually receded with the consequence that the vegetation died leaving areas of bare soil. The soil around this region is composed mainly of sand which forms a relatively smooth surface creating the backscatter return seen in the images. These areas have been classified as floodplain.

The area to the right of this has a higher return than the bare soil but a lower return than the reeds and papyrus and this has been classed as savannah.

In the images 1 (Fig. 5) and 2 (dry season) which feature Lake Bangweulu, the lake appears of a lighter tonality and therefore of a higher backscatter return than one could expect. Open water in SAR images usually appears dark.

There are exceptions to this, one of which is created by wind action. Wind on large stretches of water produces waves and generally the longer the reach the higher the waves. These waves cause the roughening of the surface and therefore produce a greater backscatter return (see Methodology).

Lake Bangweulu (inc. Lakes Walilupe and Chifanauli) has an area of 2 221 km^2 as calculated from the image. A previous study estimated the area to be 2 531 km^2, the maximum length 74 km and the maximum width 23 km (Toews, 1975). On image 2, another lake is shown, Lake Kampolombo which, although it has a much smaller surface area, shows the same phenomena. Its surface area has been estimated at 155

A Detail of Image 5 (Dry Season) Showing Different Coverage Classes.

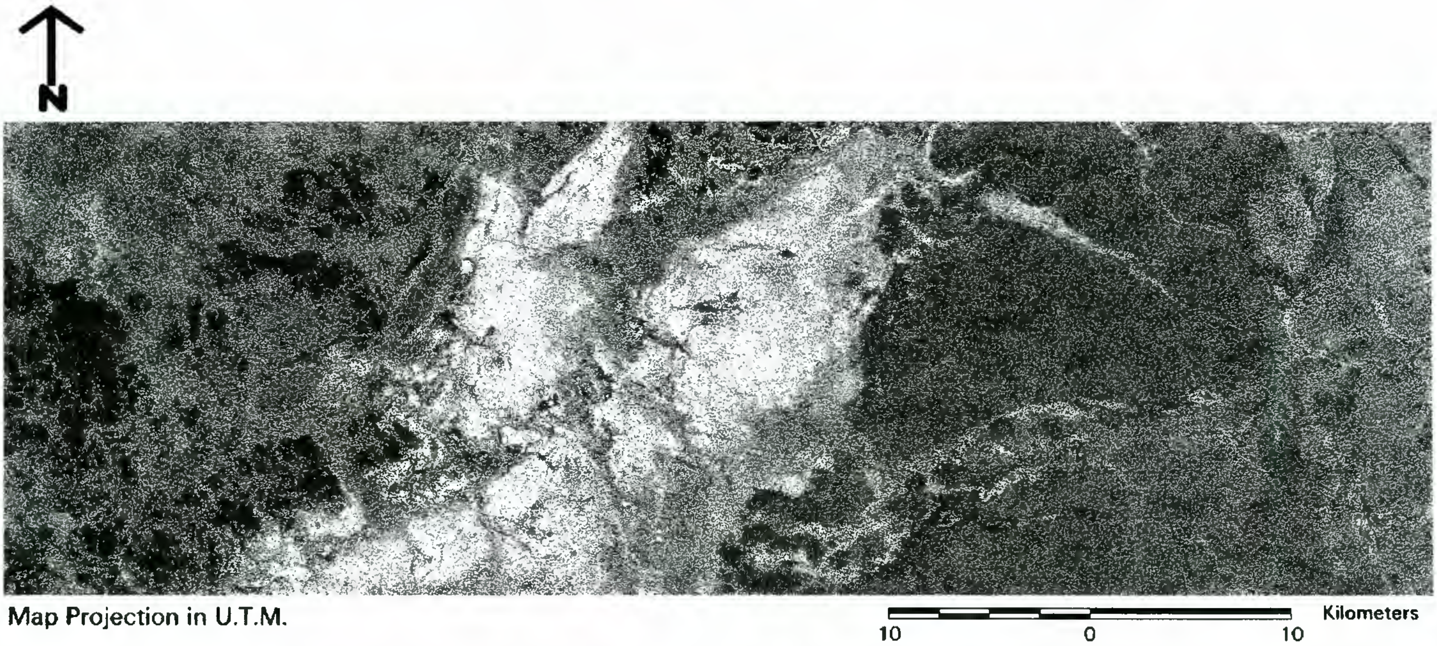
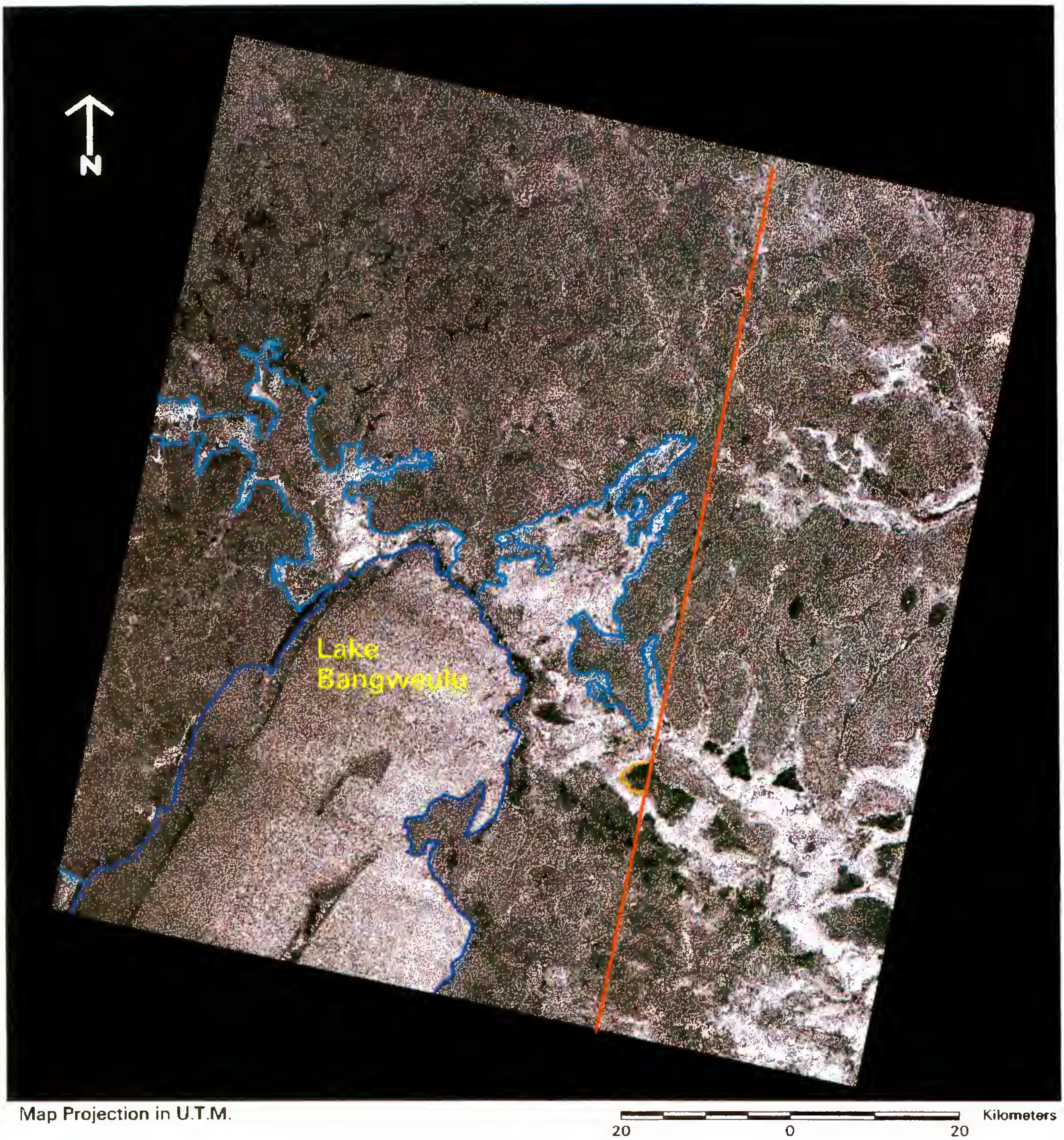


Fig. 4

ERS SAR Image 15/6/94 (Dry Season) Showing Lake Bangweulu, Zambia, and the Boundaries of Inundated Areas and Bare Soil of the Surrounding Wetlands.

Image 1



Lake Bangweulu area = 1 531 sq km

inundated area = 1 281 sq km

bare soil area = 74 sq km

boundary of overlapping image 4 (5/7/94). The area calculations do not include the area to the right of the line.

Fig. 5

km^2 , its maximum length at 29 km, and its width at 5 km (Toews, 1975). In both cases the reach would be very long with a potential of creating waves.

Rainfall Data

Rainfall data has been difficult to collect for Zambia, with large gaps in information in recent years at some stations. This has also been the case with the stations around the Bangweulu area. However, some data have been found. The chart (Fig. 6) depicts the previous six wet seasons, including 1993/94 which would have affected the wetland environment appearing in the seven dry season images. The station of Kasama is located to the north east and covers part of the Chambeshi catchment whilst the station of Mansa is located to the west of Lake Bangweulu covering some of the lesser catchments.

Added to this is the information gained from the meteorological satellite data which suggests that the 93/94 wet season was an average one.

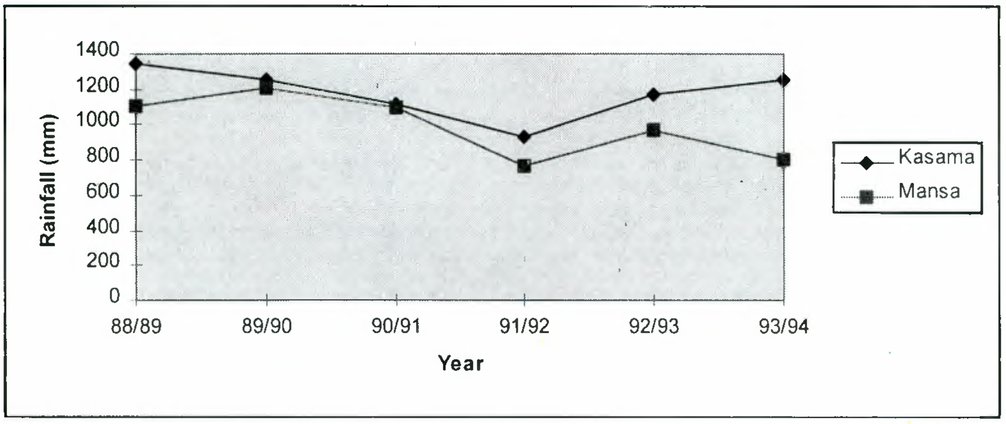


Fig. 6: Rainfall data from stations around Bangweulu

Interpretation

The AVHRR data (Fig. 7) shows a good relation to the SAR data particularly the shape and appearance of the borders which demonstrate an encouraging overall similarity.

NOAA AVHRR Image 28/6/94 (Dry Season) of Lake Bangweulu, Zambia, and the Boundaries of Inundated Areas and Bare Soils of the Surrounding Wetlands

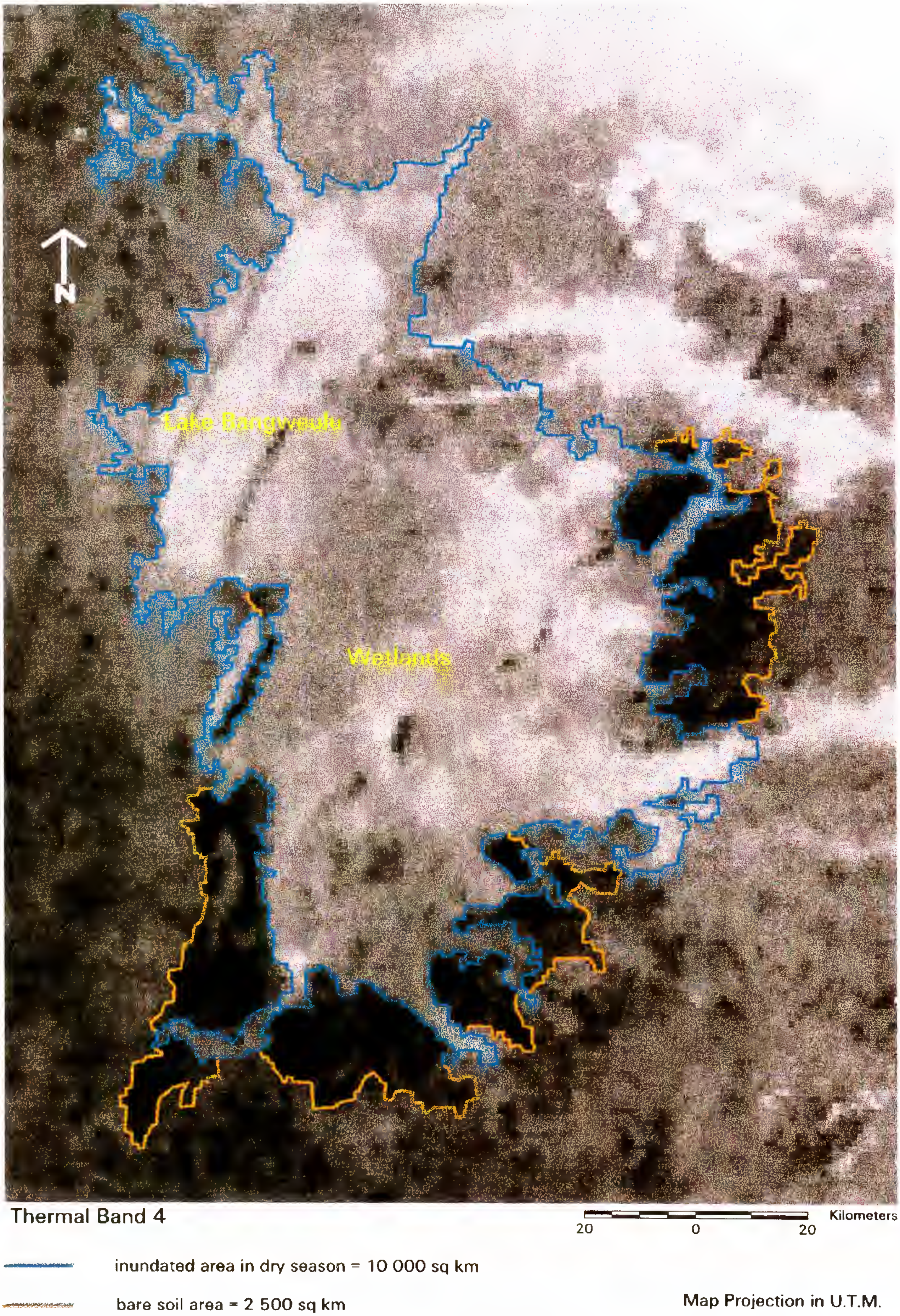


Fig. 7

Table 4: Area measurements (dry season)

ERS SAR

Image Number	Inundated Area km^2	Bare Soil Area km^2	Total km^2
1	2 812	74	2 886
2	2 478	130	2 608
3	149	218	367
4	808	675	1 483
5	3 929	2 134	6 063
6	92	541	634
7	217	--	217
Interpolated data	551	492	1 043

Comparison of Area Totals:-

Data Type	Date	Season	Inundated Area km^2	Bare Soil Area km^2	Total km^2
ERS SAR	June/July 1994	Dry	11 036	4 264	15 300
NOAA AVHRR	28 June 1994	Dry	10 000	2 500	12 500

When comparing the areal measurements, however (Table 4), the AVHRR data have produced a distinct reduction in surface area in comparison with the SAR images, most particularly with the class of bare soil. The percentage differences show that in the case of inundated areas there is a 10% increase in the area calculated by SAR as compared to AVHRR. In the case of bare soil, there is a 70% increase. The difference in pixel resolution must play a great part in the discrepancy. The AVHRR at 1 100 m resolution depicts 88 times less detail than the SAR images. For example, an area of 1 100 m^2, viewed by both AVHRR and SAR, will produce one AVHRR pixel classified according to the dominating class; the SAR image, on the other hand, will produce 7 744 pixels showing a mixture of classes. This could explain the difference as regards the inundated areas.

Another explanation which should be considered is that georeferencing of the AVHRR image is not very accurate. This is due to a limited number of points for georeferencing to be found on the grid which is emphasised by the fact that the image covers such a large area. The pixel size also does not assist in this accuracy. The areal measurements would consequently be affected by this imprecise georeferencing.

This might explain the difference in calculated areas but one should expect, consequently, to find a comparative difference as regards bare soil. This, however, is not the case. Another explanation must be found. This was done by analysing the locations of the differences in bare soil. It was found that the bare soil areas in the AVHRR image (thermal inertia approach and NDVI) did not extend as far out from the wetlands as the SAR images depicted. This suggests that the thermal inertia differences are not so large between the bare soil and the savannah as are the differences between inundated areas and bare soil. This would seem logical, the differences in thermal inertia becoming less as the bare soil merges into savannah and the vegetation begins to encroach on the bare soil.

The differentiation between bare soil and savannah is heightened by the use of SAR, the borders being defined and therefore the digitising is easier. AVHRR thermal inertia produces a gradual blurring between the borders which produces an added problem when digitising, requiring a certain amount of user discretion.

Mosaic

An uncontrolled mosaic of the seven dry season ERS-SAR images, including interpolation for the missing data, was prepared to have an overview of the whole wetland system (Fig. 8).

3.2 Wet Season

Classification

The classification is the same as for the dry season with a few additions as explained in the interpretation below.

Measurements

The comparison below is taking the common areas in image 5 (dry) and image 2 (wet) and then extending the area in image 2 to the left to be comparable to image 5 (Fig. 9 and 10).

Table 5 : Area measurements (wet season)

Image Number	Inundated Area km^2	Bare Soil Area km^2	Total Area km^2
5 (dry)	3 748	1 975	5 723
2 (wet)	7 344	--	7 344

As can be seen from the table above, the inundated area in image 2 (wet) is much greater than even the total in image 5 (dry).

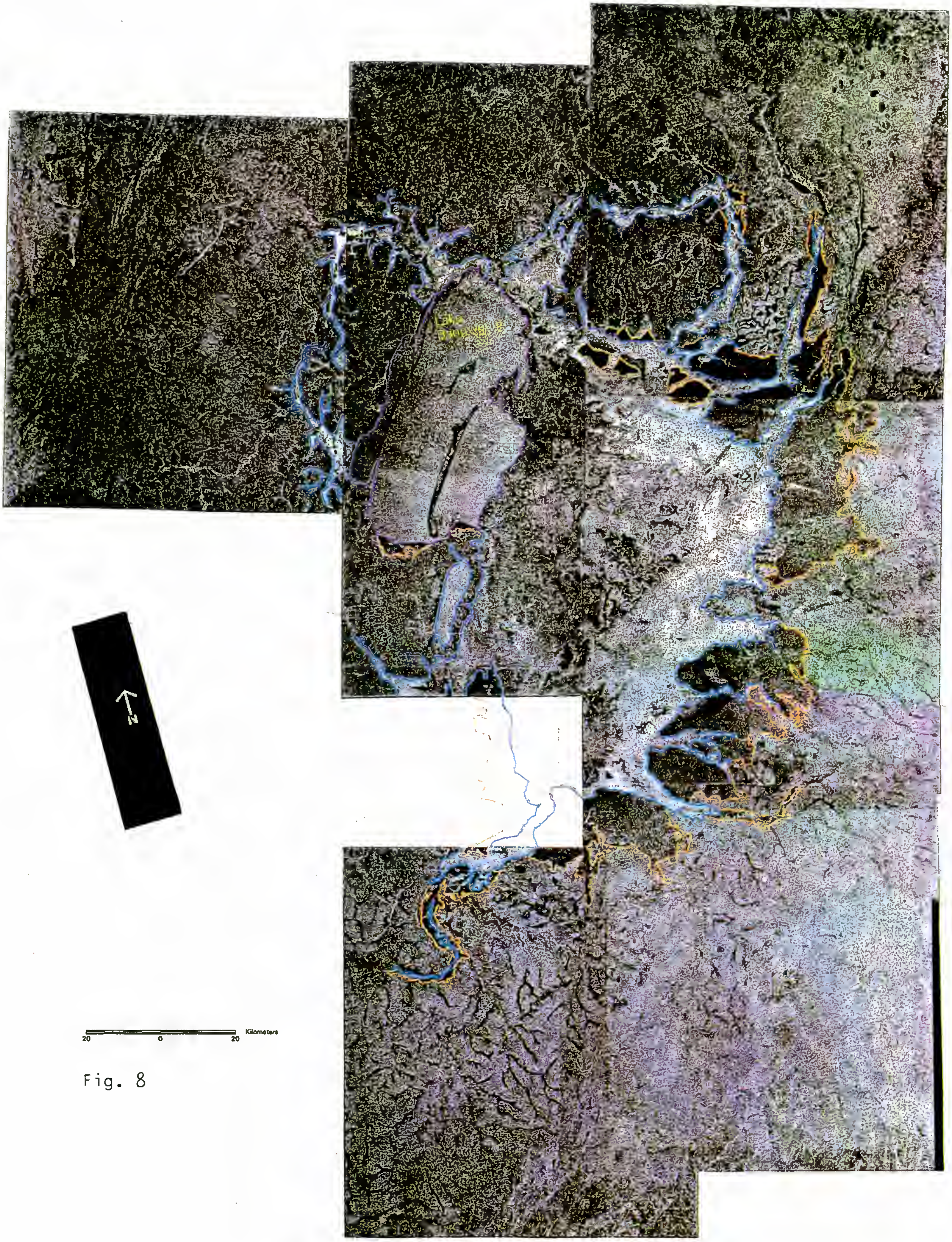
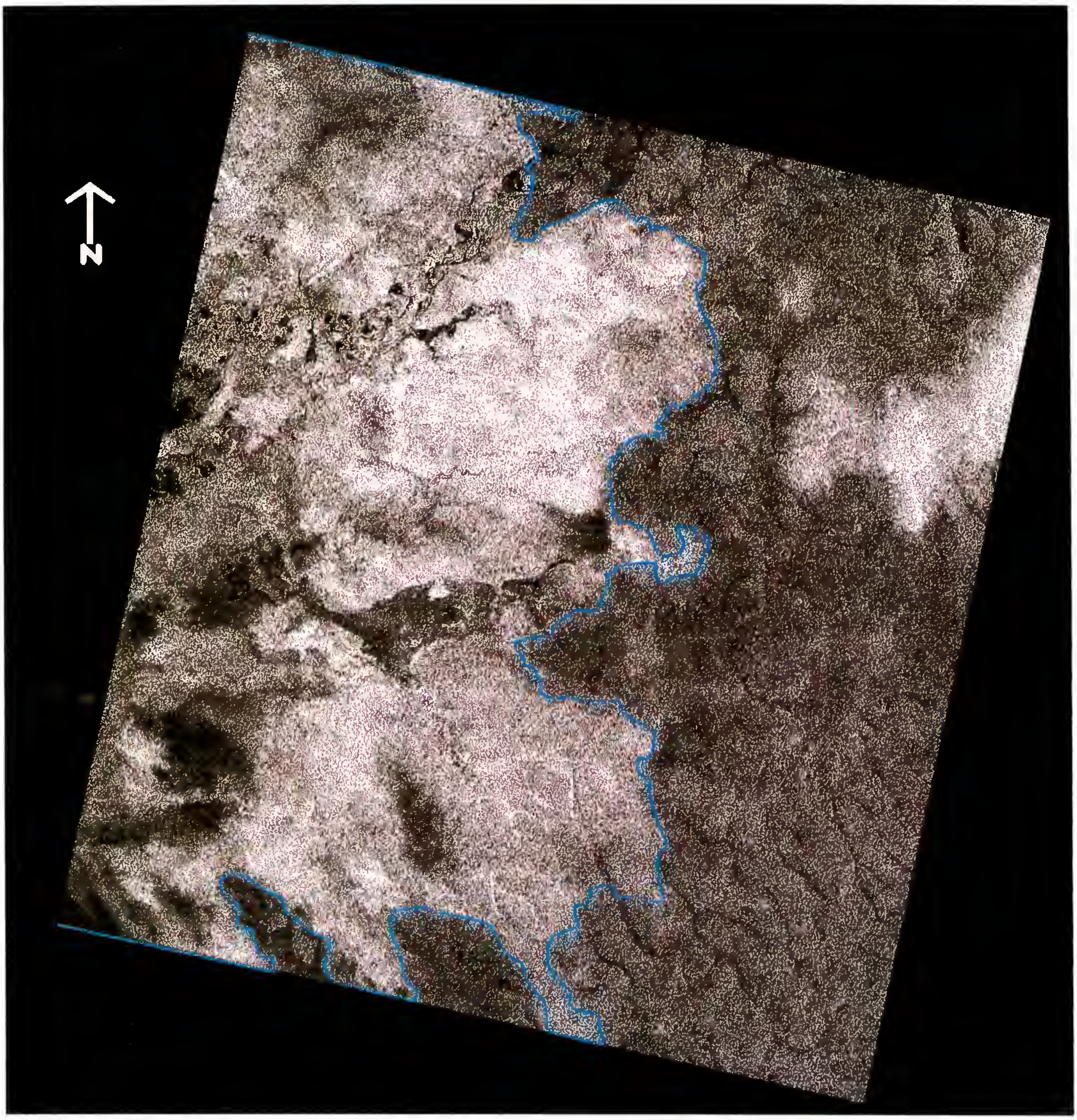


Fig. 8

ERS SAR Image 19/11/95 (Wet Season) Showing the Inundated Areas of the Wetlands Surrounding Lake Bangweulu, Zambia.

Image 2



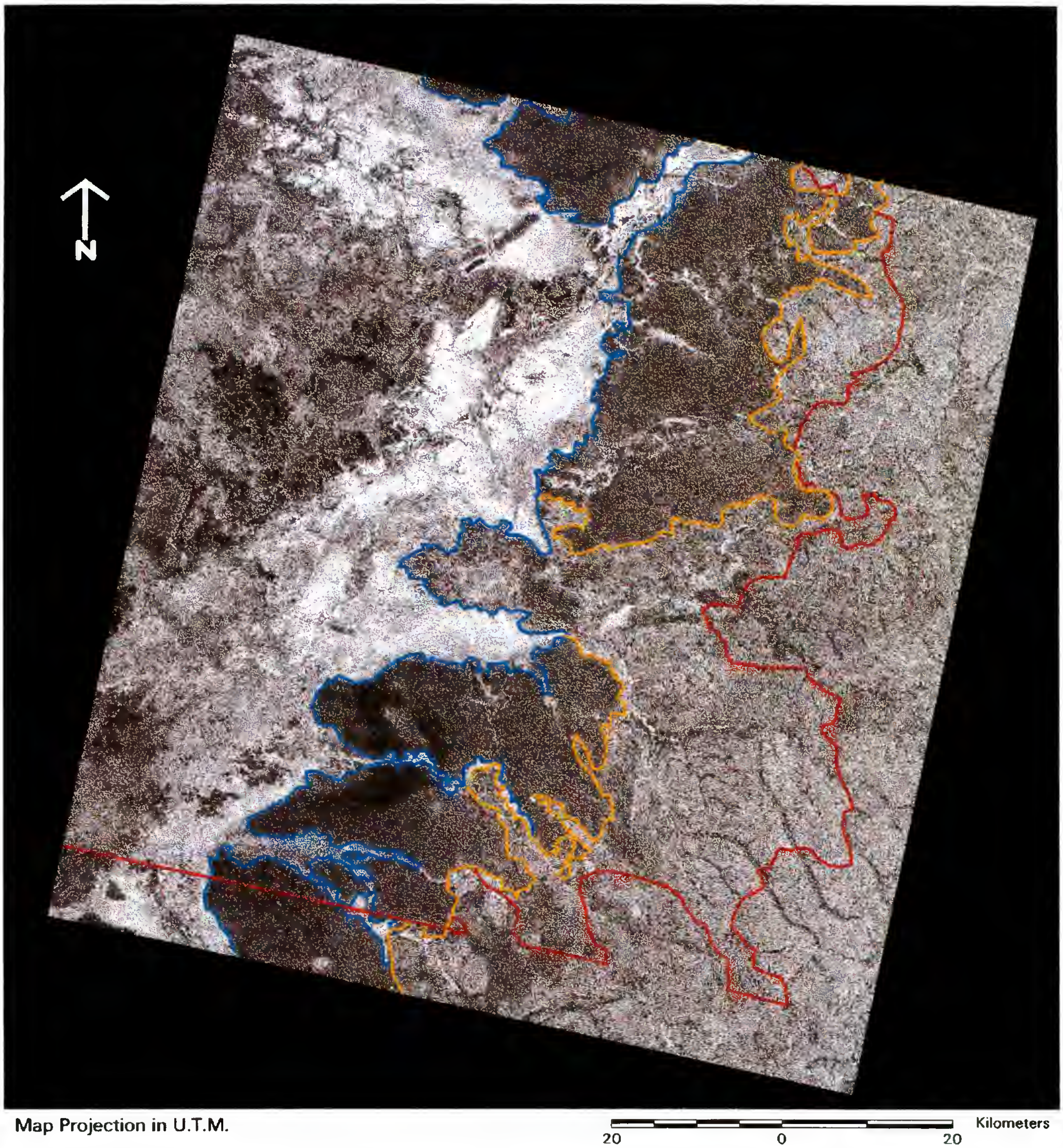
Map Projection in U.T.M.

20 0 20 Kilometers

inundated area in wet season

Fig. 9

ERS SAR Image 5/7/94 (Dry Season) Showing Lake Bangweulu, Zambia, and the Boundaries of Inundated Areas and Bare Soil of the Surrounding Wetlands.



inundated area in dry season = 3 812 sq km

bare soil area in dry season = 2 252 sq km

inundated area in wet season = 7 344 sq km. Dry and wet season images do not overlap exactly.

Fig. 10

Rainfall Data

There is no rainfall data for the period 1995 from the stations around Lake Bangweulu. However, looking back at previous years over the same period (Fig. 11), it can be seen that around November the rains are just starting and have not reached the peak monthly rainfall. This is supported by satellite data for 1995 which show that although they started early the rains were patchy and erratic.

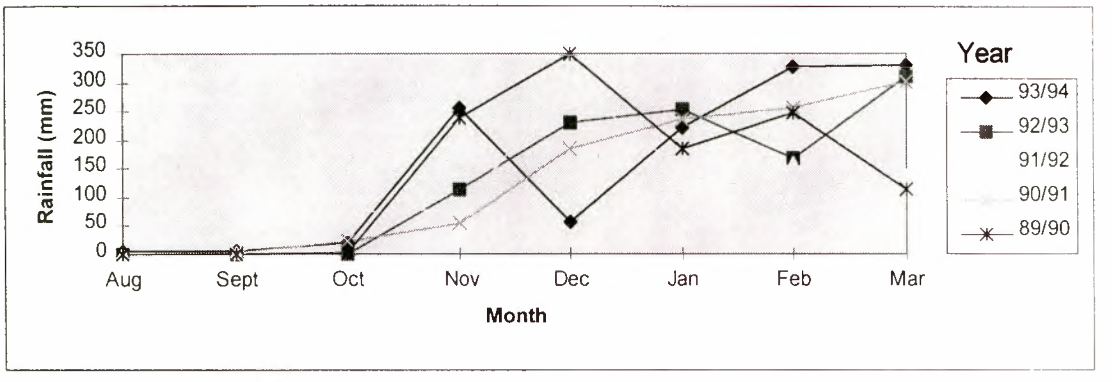


Fig. 11: Rainfall data from Kasama station during wet season

Interpretation

Only one wet season image was digitised because only one showed a significant difference to the equivalent dry season image and, therefore, permitted a comparison.

The other image, number 1 (wet season), acquired on 7 December, showed that there was little expansion of the vegetation from dry to wet seasons in this area. Both images, however, showed interesting features.

The first that can be seen clearly is that on image 1, Lake Bangweulu and Lake Kampolombo have a much darker tonality than in the dry season. If it is assumed that on the day the dry season image was acquired it was windy, it can also be assumed that on the wet season image it was not. The differences are very distinct (Fig. 12).

In image 2, it can be seen that the brighter areas have spread, which suggests that the surface has become rougher. By our earlier classification of the dry season, this high backscatter return would be attributed to the spread of vegetation such as reeds and papyrus. These plants, however, are associated with inundated areas and shallow standing water. According to the time of the year and the rainfall data for this period, there would have occurred a limited expansion of the flooded areas at this time, by no means the amount suggested by the growth in vegetation in image 2. Indeed, by the measurements listed above, the inundated area in image 2 (wet) is greater than the total of inundated and bare soil area combined in image 5 (dry). There therefore has to be considered a new classification for this period.

A multitemporal image was used to assist with the new classification. Table 6 shows how some of the classes will appear on the multitemporal image (Fig. 13).

ERS SAR Image 7/12/95 (Wet Season) Showing Lake Bangweulu, Zambia, and the Surrounding Wetlands.

Image 1

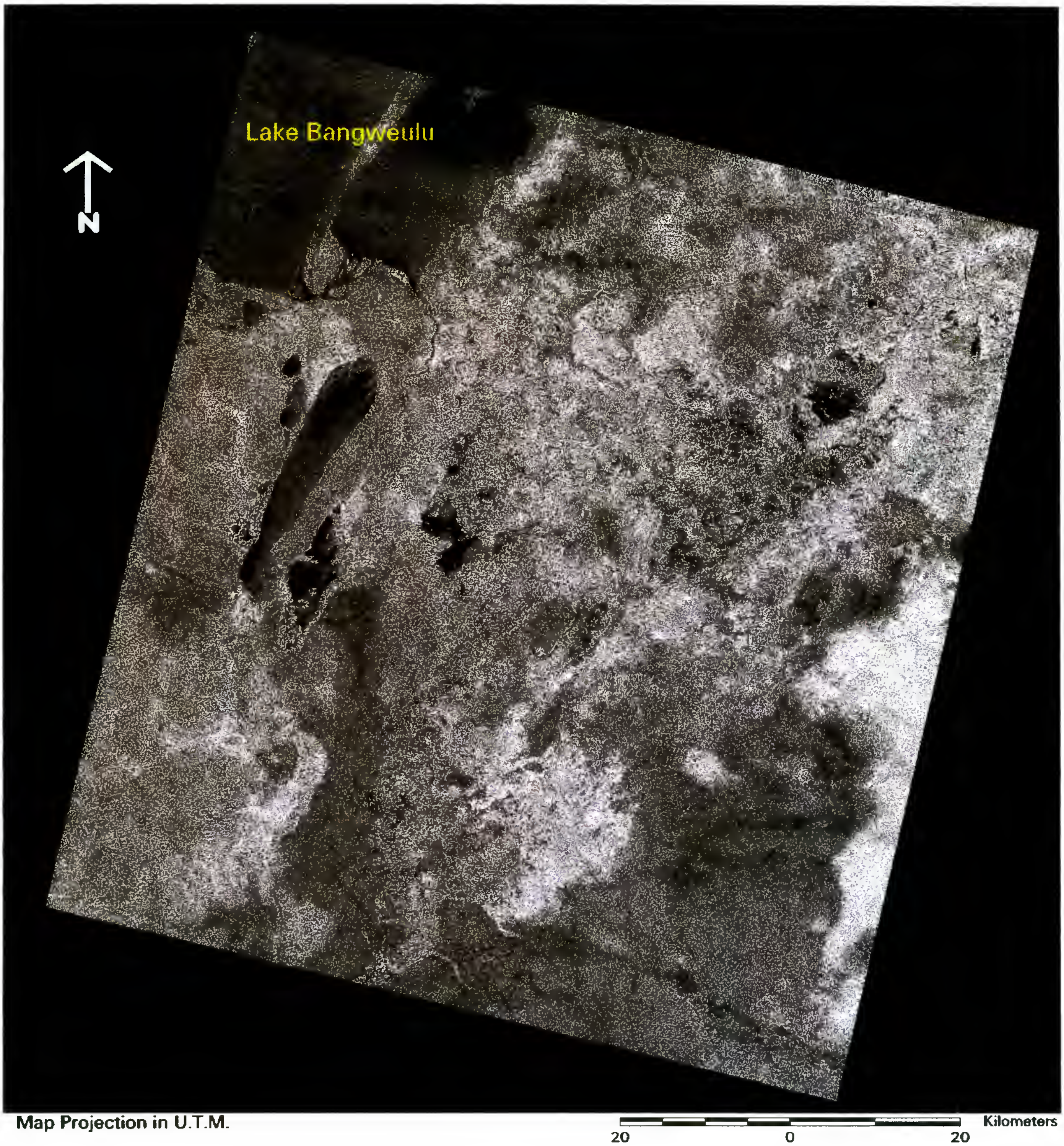


Fig. 12

Table 6 : Table of colours

Image 5 red	Image 2 green	Image 2 (1st p.c.) blue	MULTITEMPORAL COLOUR
white	white	white	white
white	black	black	red
black	white	white	cyan
grey	white	white	light cyan
light grey	dark grey	dark grey	grey/red
black	black	black	black

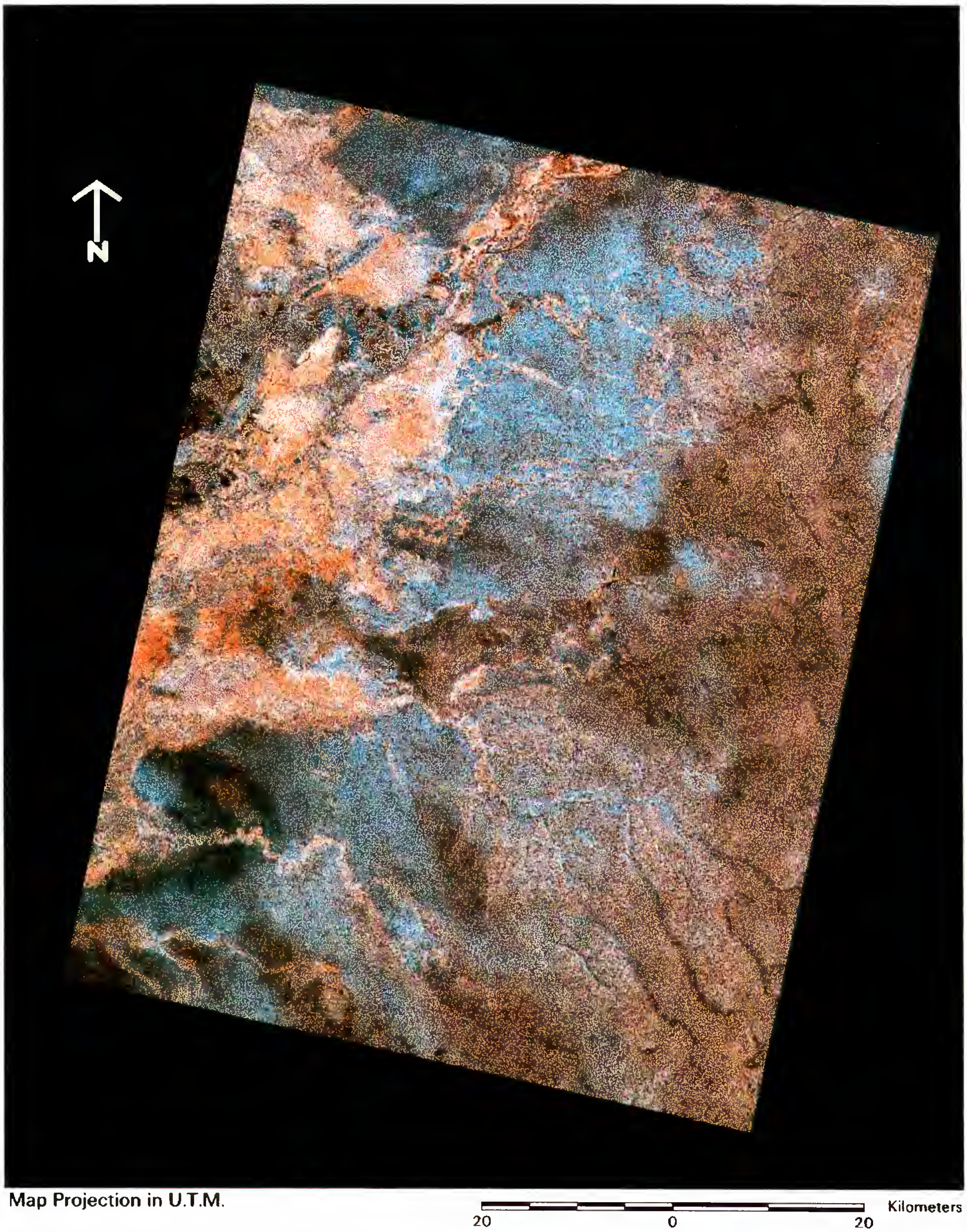
To the left of the multitemporal image there are sections of white and red. These, respectively, are areas in which there were and still are reeds; or which were once reeds but have now changed to other forms of lower standing vegetation or to open water. Areas of strongly concentrated cyan are regions which were bare but now have some form of standing vegetation. The areas further to the right of less concentrated cyan are expanses of new growth in the floodplain.

The likely interpretation is that this growth is of new vegetation associated with the floodplain such as *Setaria sphacelata*, *Hyparrhenia filipendula* in dryer areas, and *Leersia hexandra* which appears along streams of the floodplain. The continuous spreading of the high backscatter (and therefore vegetation) from the wetlands outward indicates that the water in the wetlands is increasing. This is not enough to cause inundation, but is enough to percolate through the soil from the wetland to the savannah increasing soil moisture. The greatest concentrations of new growth are on the bare soil where there is no competition from other plants and along the thalwegs where there is more water/soil moisture available.

The greatest expansion of the wetland is in image 2 (wet). This also concurs with the equivalent dry season image 5 which has the greatest area of bare soil and, as referred to previously, is associated with the wet season expansion of the inundated area. This locality of the wetlands is supplied from the northeast, from the Rift Valley Highlands on the border with Tanzania, by the Chambeshi, Lubanseshi and Lutingila Rivers. It is also supplied from the southeast from the Muchinga Escarpment whose waters drain into the wetlands through the Munikashi, Kanchibya, Lumbatwa and Lukulu Rivers. These regions are the two biggest catchments for Lake Bangweulu. The first expansion of vegetation in this part of the wetlands, which is supplied by these rivers, would be a natural occurrence even with limited rainfall. This would also explain the lack of new growth in image 1 (wet) which is supplied by lesser catchments.

Furthermore, in this region there is a practice of scrub burning carried out every year. Immediately after this burning there is a regrowth. Image 2 (wet), therefore, could be showing this regrowth; however, it would be necessary to obtain images in this period of burning to confirm the precise location and extent. This, consequently, cannot be submitted into our conclusions.

ERS SAR Multitemporal Image Showing the Wetlands Surrounding Lake Bangweulu, Zambia.



Band 1 - 05/July/94 (dry season) = red
Band 2 - 19/Nov/95 (wet season) = green
Band 3 - 19/Nov/95 first principal component = blue

Fig. 13

CHAPTER 4

CONCLUSION

The study compared over the same wetland system two sets of data, NOAA AVHRR and ERS-SAR having very different spatial resolutions and characteristics. The data for the 1994 dry season were all acquired within a very limited time frame and thus represented the same situation on the ground.

Comparison of area measurements by the two methodologies produced similar results for the inundated area, the ten percent difference of NOAA results being clearly due to the large pixel size and imprecise georeferencing. This, however, is largely compensated by the low cost of data and ease of processing.

Being the thermal inertia approach dependent on good weather conditions, microwave data can provide the needed information during wet season, when the wetland reaches its maximum expansion. Table 7 summarizes the positive aspects and constraints of the two methodologies for wetland monitoring.

Table 7: Evaluation of the two methodologies

NOAA AVHRR:

Pros:-
1) Only one AVHRR image is needed for a large study area.
2) It can distinguish inundated areas.
3) Cost is relatively small.
4) The time spent on digitising an image is minimal.

Cons:-
1) The accuracy is reduced by the larger pixel resolution.
2) The thermal inertia approach does not resolutely distinguish between bare soil and vegetated soil consequently digitising is as accurate as the user.
3) The georeferencing is not as accurate.
4) Choice of images is limited by weather conditions.

ERS SAR:

Pros:-
1) All weather capability.
2) It is able to clearly distinguish between different classes therefore digitising is easier.
3) Different types of vegetation can be classified.
4) The accuracy is increased by the pixel resolution.

Cons:-
1) Several more images are needed to cover a large area.
2) Therefore it takes more time to digitise the whole area.
3) If non-geocoded images are used, georeferencing can take some time.
4) The cost is greater.

It can be clearly seen that ERS SAR images can be used to define differences within a wetland system from which can be interpreted areas of changing vegetation; areas of open water; and areas of bare soil. The resolution of 12.5 m allows for this interpretation to be performed in great detail. The added benefit of SAR when studying areas of wetland is the ability to obtain information despite weather conditions, i.e. cloud or rain, over the area.

NOAA AVHRR thermal inertia approach has proven to be effective in monitoring wetland systems as has been experienced by a separate, previous study. In a comparison with SAR images, however, there have been some discrepancies. It has been found that AVHRR images can give an overall idea of area measurements and boundary locations. If more precision is required or if an area needs to be anlysed in depth, for example, the classification of vegetated areas, then SAR images offer a better facility. The choice between SAR and AVHRR depends upon the purpose of the study and the accuracy required. The two formats can work well together as it has been demonstrated in this study, the AVHRR providing a quick, clear, initial interpretation and the SAR providing the detail and accuracy.

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